



INVESTOR IN PEOPLE

The Patent Office  
Concept House  
Cardiff Road  
Newport  
South Wales  
NP10 8QQ

**BEST AVAILABLE COPY**

REC'D 20 JAN 2004

WIPO PCT

I, the undersigned, being an officer duly authorised in accordance with Section 74(1) and (4) of the Deregulation & Contracting Out Act 1994, to sign and issue certificates on behalf of the Comptroller-General, hereby certify that annexed hereto is a true copy of the documents as originally filed in connection with the patent application identified therein.

In accordance with the Patents (Companies Re-registration) Rules 1982, if a company named in this certificate and any accompanying documents has re-registered under the Companies Act 1980 with the same name as that with which it was registered immediately before re-registration save for the substitution as, or inclusion as, the last part of the name of the words "public limited company" or their equivalents in Welsh, references to the name of the company in this certificate and any accompanying documents shall be treated as references to the name with which it is so re-registered.

In accordance with the rules, the words "public limited company" may be replaced by p.l.c., plc, C. or PLC.

Re-registration under the Companies Act does not constitute a new legal entity but merely subjects the company to certain additional company law rules.

Signed

Dated 6 January 2004

**PRIORITY DOCUMENT**  
SUBMITTED OR TRANSMITTED IN  
COMPLIANCE WITH  
RULE 17.1(a) OR (b)

Patents Form 1/77  
 Patents Act 1977  
 (Rule 16)

RECEIVED BY FAX

20 DEC 2002

The  
 Patent  
 Office

200FC02 E77268-1 002871  
 1/77  
 P01-7700 00-02 9633.3

# Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)

The Patent Office

Cardiff Road  
 Newport  
 South Wales  
 NP9 1RH

1. Your reference  
 101.0049

2. Patent application number  
 (The Patent Office will fill in this part)  
 0229633.3  
 20 DEC 2002

3. Full name, address and postcode of the or of each applicant (underline all surnames)  
 Jaime A Castano  
 Sensor Highway Limited  
 Gamma House, Chilworth Science Park  
 Southampton  
 Hampshire SO16 7NS

Patents ADP number (if you know it)

If the applicant is a corporate body, give the country/state of its incorporation

085314 09001

4. Title of the invention  
 SYSTEM AND METHOD TO MINIMIZE MODULATION INSTABILITY

5. Name of your agent (if you have one)  
 "Address for service" in the United Kingdom to which all correspondence should be sent (including the postcode)  
 Jaime A Castano  
 Sensor Highway Limited  
 Gamma House  
 Chilworth Science Park  
 Southampton  
 Hampshire SO16 7NS

Wayne I Kanak  
 Gamma House  
 Enterprise Road  
 Chilworth Science Park  
 Southampton  
 Hampshire  
 SO16 7NS

Patents ADP number (if you know it)

(S117) 8-12-03

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and (if you know it) the or each application number

Country	Priority application number (if you know it)	Date of filing (day / month / year)
---------	--	-------------------------------------

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing (day / month / year)
-------------------------------	-------------------------------------

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? (Answer 'Yes' if

Yes

- a) any applicant named in part 3 is not an inventor, or
- b) there is an inventor who is not named as an applicant, or
- c) any named applicant is a corporate body.

See note (d)

## Patents Form 1/77

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form -  
 Description 9 ✓  
 Claim(s) 5 ✓  
 Abstract 1 ✓  
 Drawing(s) 2 ✓ *one*

10. If you are also filing any of the following, state how many against each item.

Priority documents -  
 Translations of priority documents -  
 Statement of inventorship and right to grant of a patent (Patents Form 7/77) -  
 Request for preliminary examination and search (Patents Form 9/77) -  
 Request for substantive examination (Patents Form 10/77) -  
 Any other documents (please specify) -

11.

I/We request the grant of a patent on the basis of this application.

Signature

Date

20/12/2002

12. Name and daytime telephone number of person to contact in the United Kingdom

Jaime A Castano  
 02380 765512

## Warning

After an application for a patent has been filed, the Comptroller of the Patent Office will consider whether publication or communication of the invention should be prohibited or restricted under Section 22 of the Patents Act 1977. You will be informed if it is necessary to prohibit or restrict your invention in this way. Furthermore, if you live in the United Kingdom, Section 23 of the Patents Act 1977 stops you from applying for a patent abroad without first getting written permission from the Patent Office unless an application has been filed at least 6 weeks beforehand in the United Kingdom for a patent for the same invention and either no direction prohibiting publication or communication has been given, or any such direction has been revoked.

## Notes

- If you need help to fill in this form or you have any questions, please contact the Patent Office on 0645 500505.
- Write your answers in capital letters using black ink or you may type them.
- If there is not enough space for all the relevant details on any part of this form, please continue on a separate sheet of paper and write "see continuation sheet" in the relevant part(s). Any continuation sheet should be attached to this form.
- If you have answered 'Yes' Patents Form 7/77 will need to be filed.
- Once you have filled in the form you must remember to sign and date it.
- For details of the fee and ways to pay please contact the Patent Office.

## SYSTEM AND METHOD TO MINIMIZE MODULATION INSTABILITY

### BACKGROUND

The invention generally relates to the use of fiber optic sensors in a variety of environments. More particularly, the invention relates to the use of such sensors in a way which corrects the modulation instability that is generated when greater amounts of power are launched into the relevant fiber.

A distributed fiber optic sensor enables a measurand (usually temperature) to be characterised along the length of the fiber as a continuous function of distance. Distributed temperature sensors are used in the following industries and processes: oil well production, electrical power cables, industrial processes, pipelines, fire alarms and tunnels.

In optical time domain reflectometry (OTDR) type sensors, a short pulse of light is launched into the sensing fiber. As the pulse propagates along the fiber a small fraction of light is scattered back towards the sending end. The processing electronics measures the characteristics of the backscattered light as a function of time relative to the input pulse. As the propagation time of the light is known, the perturbations of its characteristics may be spatially resolved along the fiber.

In Brillouin OTDR (BOTDR) the light scattered back is as a result of Brillouin scattering. Both the intensity and frequency shift of the Brillouin scattered light are dependent on temperature and strain. Therefore by analysing these parameters it is possible to realise a distributed temperature and/or strain sensor.

The performance of OTDR type sensors is critically dependent on the signal-to-noise

ratio (S/N) at the receiver which is directly dependent on the power of the launched pulse. The upper limit to the power of the launched pulse is determined by the onset of non-linear effects in the fiber. For BOTDR systems the first non-linear effect which degrades system performance as the pulse power is increased is that known as modulation instability. Modulation instability is a result of the intense electric field of the optical pulse causing a change in the refractive index of the fiber. This causes a change in the phase of the light, effectively modulating it and results in the generation of sideband signals. The sidebands then interfere at the receiver with the wanted Brillouin signals and degradation of the S/N occurs leading to possible inaccuracies in the measurements.

Other types of fiber optic sensing systems are also susceptible to modulation instability. These include Raman OTDR systems, Brillouin or Raman optical frequency reflectometry systems, fiber Bragg grating systems, interferometric systems, polarimetric systems, intensity systems, and distributed, single-point, or multi-point systems.

The prior would therefore benefit from a fiber optic sensing system in which optical signals of greater power can be launched into the relevant fiber without the onset of modulation instability.

Thus, there exists a continuing need for an arrangement and/or technique that addresses one or more of the problems that are stated above.

### SUMMARY

According to a first aspect, the present invention comprises a fiber optic sensing system for use in a remote location, comprising: an optical fiber adapted to carry an optical signal from a starting location towards a remote location; the fiber adapted to transmit at least one information-carrying signal from the remote location towards the starting location; the information-carrying

signal carrying information related to a parameter that is sensed in the remote location; the fiber operated in a region of negative chromatic dispersion; and the optical signal being at a power level sufficient to generate modulation instability if the fiber were operated in a region of positive chromatic dispersion.

5. According to a second aspect, the invention is a method for sensing a parameter in a remote location, comprising: providing a fiber; carrying an optical signal through the fiber from a starting location towards a remote location; operating the fiber in a region of negative chromatic dispersion; carrying the optical signal at a power level sufficient to generate modulation instability if the fiber were operated in a region of positive chromatic dispersion; sensing a parameter in the remote location; and transmitting at least one information-carrying signal through the fiber from the remote location towards the starting location, the information-carrying signal carrying information related to the parameter.

### BRIEF DESCRIPTION OF THE DRAWING

Fig. 1 is a plot of the spectrum of the optical signal using a prior art fiber optic sensor and system.

Fig. 2 is a plot of the spectrum of the optical signal (decibel versus wavelength) at a similar power setting as that of Figure 1 using a dispersion shifted fiber.

Fig. 3 is a schematic of the present invention used in a wellbore.

Fig. 4 is a schematic of the present invention used along a pipeline.

### DETAILED DESCRIPTION

A more detailed explanation of modulation instability will first be provided followed by the present invention's system and method to minimize such instability.

Optical fibers exhibit what is known as chromatic dispersion. Chromatic dispersion is the derivative of the transit time of an optical pulse with respect to wavelength. In turn, this phenomenon is caused by the refractive index changing with wavelength. A second effect, the Kerr effect, modifies the refractive index as a function of the power density in the core of the fiber. When the refractive index change caused by the Kerr effect matches the chromatic dispersion, then small variations in power become amplified and ultimately result in a chaotic signal with increasingly wide sidebands (see 22 in Fig. 1 and further explanation below) as the power level and the fiber length increase ("modulation instability"). Modulation instability results from four-wave mixing, where the phase matching is provided by the non-linear changes in refractive index compensating chromatic dispersion. Modulation instability only occurs in a wavelength region where chromatic dispersion has a positive sign. It should also be noted that, in the positive dispersion region, the most effective modulation instability occurs where the dispersion is small, since only low levels of Kerr-non-linearity are needed to compensate the dispersion in this case. The phenomenon of modulation instability is well known in telecommunications and is described further by G.P. Agrawal in "Non-linear Fiber Optics" Academic Press, 1989, ISBN 0-12-045140-9.

Figure 1 illustrates the problems encountered with modulation instability specially when the relevant fiber is used to transmit sensing information. Figure 1 shows a plot of the spectrum of the optical signal (intensity in log-scale versus wavelength) at a given power setting using a prior art fiber optic sensor and system, such as Corning's SMF 28. Figure 1 shows at 20 the highest power that is launched into the relevant optical fiber. This peak power 20 is great

0055887 20-D-6 61-01-2

enough to cause the onset of modulation instability in the fiber, as described above. The modulation instability, in turn, causes the sidebands 22 to be generated at either side of the peak power 20. The sidebands 22 obstruct the measurement of the smaller and information-carrying signals 24, such as the Brillouin peaks shown in Figure 1. Other information-carrying signals, such as Raman scattering, may also be affected by the sidebands 22. The information-carrying signals 24 include the information that relates to the parameter that is sensed by the fiber optic sensing system. Thus, in order to measure the information-carrying signals 24, the sidebands 22 should be greatly reduced if not eliminated.

As previously discussed, modulation instability only occurs in a wavelength region where chromatic dispersion has a positive sign. The present invention thus avoids the effect of modulation instability by operating a single mode fiber sensor in the region of negative chromatic dispersion. In essence, the present invention comprises a fiber optic sensing system that greatly reduces the sidebands 22 thereby allowing the proper measurement of the information-carrying signals 24. There are various ways this can be achieved.

In one embodiment, the fiber optic sensor system is operated at wavelengths shorter than the wavelength of zero dispersion in conventional single-mode fiber. For instance, Corning's SMF 28 optical fiber has a wavelength of zero chromatic dispersion ( $\lambda_0$ ) of approximately 1311 nanometers. It follows that operating the sensing system at a wavelength shorter than  $\lambda_0$  but longer than the cut-off wavelength of the second mode (typically 1260 nanometers) prevents the onset of modulation instability.

In another embodiment, the fiber optic sensor system is operated in the region where the loss of silica fibers is at their lowest (i.e. in the vicinity of 1550nm) and in this case conventional fibers (in which chromatic dispersion is positive at this wavelength) leads to the modulation



instability problem. However, by selecting an optical fiber in which the design characteristic has been shifted to wavelengths well beyond the target operating wavelength, modulation instability can be avoided, even at 1550nm. Such fibers can be constructed by tailoring the refractive index profile, for example to increase the waveguide dispersion contribution to chromatic dispersion.

5 These fibers are commonly referred to as dispersion shifted fibers.

One type of dispersion shifted fiber is Corning's MetroCor optical fiber. Figure 2 shows a plot of the spectrum of the optical signal (intensity in log-scale versus wavelength) at a similar power setting as that of Figure 1 using a dispersion shifted fiber. As can clearly be seen, by use of the dispersion shifted fiber, the effect of modulation instability and therefore the sidebands 22 can be greatly reduced, if not eliminated.

The present invention covers the use of a wide range of fiber optic sensing systems, including Raman or Brillouin OTDR systems, Brillouin or Raman optical frequency reflectometry systems, fiber Bragg grating systems, interferometric systems, polarimetric systems, intensity systems, and distributed, single-point, or multi-point systems, although it is most beneficial where the system design requires the transmission of high-power, narrow-band light.

In addition, as is known in the art, depending on the system and sensor used, the measurand to be sensed and characterized can comprise any of a number of parameters, including temperature, strain, pressure, distributed temperature, distributed strain, distributed pressure, flow, density, resistivity, acoustic pressure, acceleration, or chemical properties.

The fiber optic sensing system 10 of the present invention may be used when the relevant fiber is the sensor itself (such as in OTDR) or when the relevant fiber transmits the sensor

information from an extrinsic sensor (such as when the fiber is connected to an external optical fiber sensor) or intrinsic sensor (such as when a fiber Bragg grating is written on the fiber).

The fiber optic sensing system 10 of the present invention may be deployed in a wellbore 30 as shown in Figure 3. A fiber 32, which may be a dispersion shifted fiber, may be deployed within a conduit 34 in the wellbore 30. The conduit 34, which can be a hydraulic control line, may be attached to a conveyance device 36, such as a production tubing or coiled tubing. The fiber 32 is optically connected to an opto-electronic unit 38 that may be located at the surface 40. The unit 38 launches the optical pulses through the fiber 32 and receives a return signal, such as backscattered light. As previously disclosed, the fiber optic sensing system 10 is operated in the region of negative chromatic dispersion (such as by employing one of the embodiments previously disclosed). Thus, the return signal will have greatly reduced sidebands 22 thereby allowing the unit 38 to measure and identify the information-carrying signals 24, such as Brillouin or Raman scattering. As is known in the art and as previously disclosed, the unit 38 provides a measurement of the relevant measurand (such as temperature, strain, or pressure) based on the reading of the information-carrying signals 24. For instance, if the measurand is distributed temperature, the unit 38 and fiber 32 provide a temperature profile along the length of fiber 32. The distributed temperature profile may be used by an operator for various purposes, such as to provide an indication of whether hydrocarbons are flowing from a formation 42 into the wellbore 30.

The present invention may also be used in conjunction with a pipeline 50 as shown in Figure 4. A fiber 52, which may be a dispersion shifted fiber, may be deployed within a conduit 54 that is disposed along the pipeline 50. The conduit 54 may be attached to the pipeline 50. The fiber 52 is optically connected to an opto-electronic unit 56. The unit 56 launches the

optical pulses through the fiber 52 and receives a return signal, such as backscattered light. As previously disclosed, the fiber optic sensing system 10 is operated in the region of negative chromatic dispersion (such as by employing one of the embodiments previously disclosed). Thus, the return signal will have greatly reduced sidebands 22 thereby allowing the unit 56 to  
5 measure and identify the information-carrying signals 24, such as Brillouin or Raman scattering. As is known in the art and as previously disclosed, the unit 56 provides a measurement of the relevant measurand (such as temperature, strain, or pressure) based on the reading of the information-carrying signals 24. If the unit 56 and fiber 52 provide a distributed temperature profile along the length of the fiber 52, the temperature profile may be used by an operator to  
1) identify the presence and location of any leaks along the pipeline 50.

Although a wellbore 30 and pipeline 50 example have been given, it is understood that the present invention including the fiber 32, 52 may be used in any other sensing environment (remote location). For instance, the present invention may be used in the following industries and processes: electrical power cables (to measure the performance of the cable), industrial processes (to measure the performance of the process), fire alarms and tunnels (to identify the presence of a fire) and civil engineering structures (to measure strain in a structure).

By reducing the effect of modulation instability, the present invention enables an operator to launch pulses over greater distances than prior art systems, and thereby enables an operator to sense a particular measurand over greater distances.

It is noted that in those embodiments in which a conduit 34, 54 houses the fiber 32, 52, the fiber 32, 52 may be pumped into the conduit 34, 54 by use of fluid drag. Essentially, the fiber 32, 53 is dragged through the conduit 34, 54 by use of hydraulic fluid pressure that is

injected into the conduit 34, 54. This pumping technique is described in U.S. Reissue Patent 37,283, incorporated herein by reference.

While the invention has been disclosed with respect to a limited number of embodiments, those skilled in the art, having the benefit of this disclosure, will appreciate numerous  
 5 modifications and variations therefrom. It is intended that the appended claims cover all such modifications and variations as fall within the true spirit and scope of the invention.

CLAIMS

What is claimed is:

1. A fiber optic sensing system for use in a remote location, comprising:

5 an optical fiber adapted to carry an optical signal from a starting location towards a remote location;

the fiber adapted to transmit at least one information-carrying signal from the remote location towards the starting location;

10 the information-carrying signal carrying information related to a parameter that is sensed in the remote location;

the fiber operated in a region of negative chromatic dispersion; and

the optical signal being at a power level sufficient to generate modulation instability if the fiber were operated in a region of positive chromatic dispersion.

2. The system of claim 1, further comprising an electro optical unit connected to the fiber.

3. The system of claim 2, wherein the unit extracts the information from the information-carrying signal.

4. The system of claim 1, wherein the optical signal is subject to a level of modulation instability that does not inhibit a proper measurement of the information-carrying signal.

5. The system of claim 1, wherein the optical signal is subject to a level of modulation instability that enables the proper measurement of the information-carrying signal.
6. The system of claim 1, wherein the parameter comprises at least one of temperature, strain, pressure, distributed temperature, distributed strain, distributed pressure, flow, density, resistivity, acoustic pressure, acceleration, or chemical properties.
7. The system of claim 1, wherein the fiber transmits the information-carrying signal from a sensor.
8. The system of claim 7, wherein the sensor is an intrinsic sensor.
9. The system of claim 7, wherein the sensor is an extrinsic sensor.
10. The system of claim 1, wherein the fiber is adapted to sense the parameter.
11. The system of claim 1, wherein the information-carrying signal comprises Brillouin scattering.
12. The system, of claim 1, wherein the remote location comprises one of a wellbore, a pipeline, an electrical power cable, an industrial process, a fire alarms, a tunnel, or a structure.
14. The system of claim 1, wherein the fiber is housed in a conduit.

15. The system of claim 14, wherein the fiber is pumped into the conduit.
16. The system of claim 1, wherein the fiber is a dispersion shifted fiber.
17. The system of claim 1, wherein the fiber is operated at wavelengths shorter than the wavelength of zero dispersion.
18. The system of claim 17, wherein the fiber is operated at wavelengths that are longer than a second mode cut-off wavelength.
19. A method for sensing a parameter in a remote location, comprising:
  - providing a fiber;
  - carrying an optical signal through the fiber from a starting location towards a remote location;
  - operating the fiber in a region of negative chromatic dispersion;
  - carrying the optical signal at a power level sufficient to generate modulation instability if the fiber were operated in a region of positive chromatic dispersion
  - sensing a parameter in the remote location; and
  - transmitting at least one information-carrying signal through the fiber from the remote location towards the starting location, the information-carrying signal carrying information related to the parameter.

20. The method of claim 19, further comprising connecting an opto electronic unit to the fiber.
21. The method of claim 19, further comprising extracting the information from the information-carrying signal.
22. The method of claim 19, wherein the carrying step comprises carrying the optical signal so that the optical signal is subject to a level of modulation instability that does not inhibit a proper measurement of the information-carrying signal.
23. The method of claim 19, wherein the carrying step comprises carrying the optical signal so that the optical signal is subject to a level of modulation instability that enables the proper measurement of the information-carrying signal.
24. The method of claim 19, wherein the parameter comprises at least one of temperature, strain, pressure, distributed temperature, distributed strain, distributed pressure, flow, density, resistivity, acoustic pressure, acceleration, or chemical properties.
25. The method of claim 19, wherein the sensing step comprises sensing the parameter with a sensor and the transmitting step comprises transmitting the information-carrying signal from the sensor.
26. The method of claim 25, wherein the sensor is an internal sensor.



27. The method of claim 25, wherein the sensor is an external sensor.
28. The method of claim 19, wherein the sensing step comprises sensing the parameter with the fiber.
29. The method of claim 19, wherein the information-carrying signal comprises Brillouin scattering.
30. The method of claim 19, wherein the remote location comprises one of a wellbore, a pipeline, an electrical power cable, an industrial process, a fire alarms, a tunnel, or a structure.
31. The method of claim 19, further comprising housing the fiber in a conduit.
32. The method of claim 31, further comprising pumping the fiber into the conduit.
33. The method of claim 19, wherein the fiber is a dispersion shifted fiber.
34. The method of claim 19, further comprising operating the fiber at wavelengths shorter than the wavelength of zero dispersion.
35. The method of claim 34, further comprising operating at wavelengths that are longer than a second mode cut-off wavelength.

## SYSTEM AND METHOD TO MINIMIZE MODULATION INSTABILITY

## ABSTRACT OF THE DISCLOSURE

The present invention comprises the use of a fiber in a sensing optical fiber system operated in a region of negative chromatic dispersion to minimize modulation instability thereby enabling the identification and measurement of the information-carrying signals. The present invention may be used in a variety of sensing environments.

Figure 1

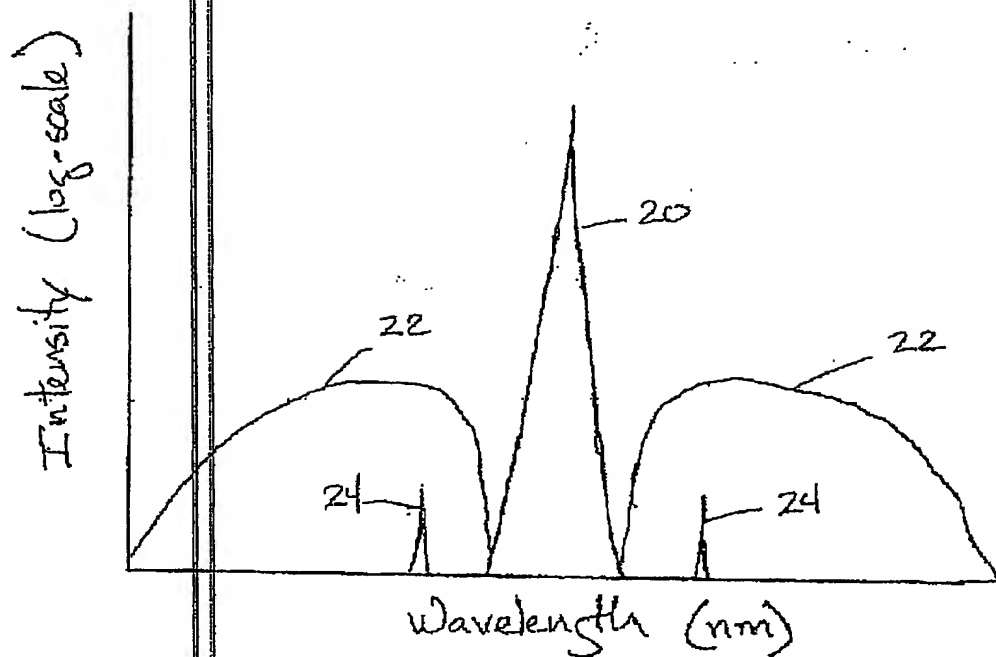
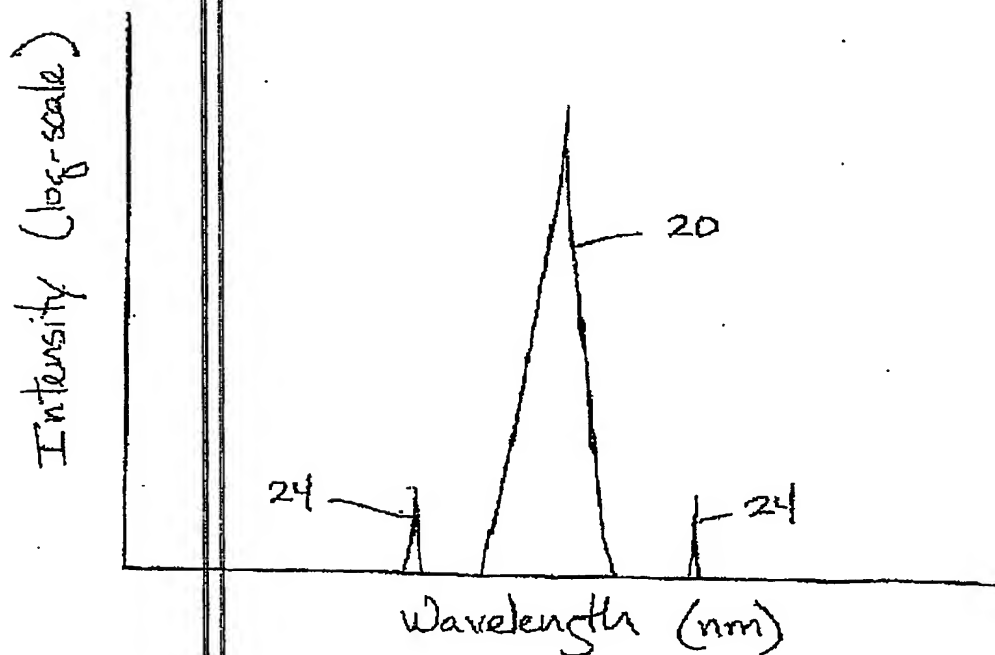


Figure 2



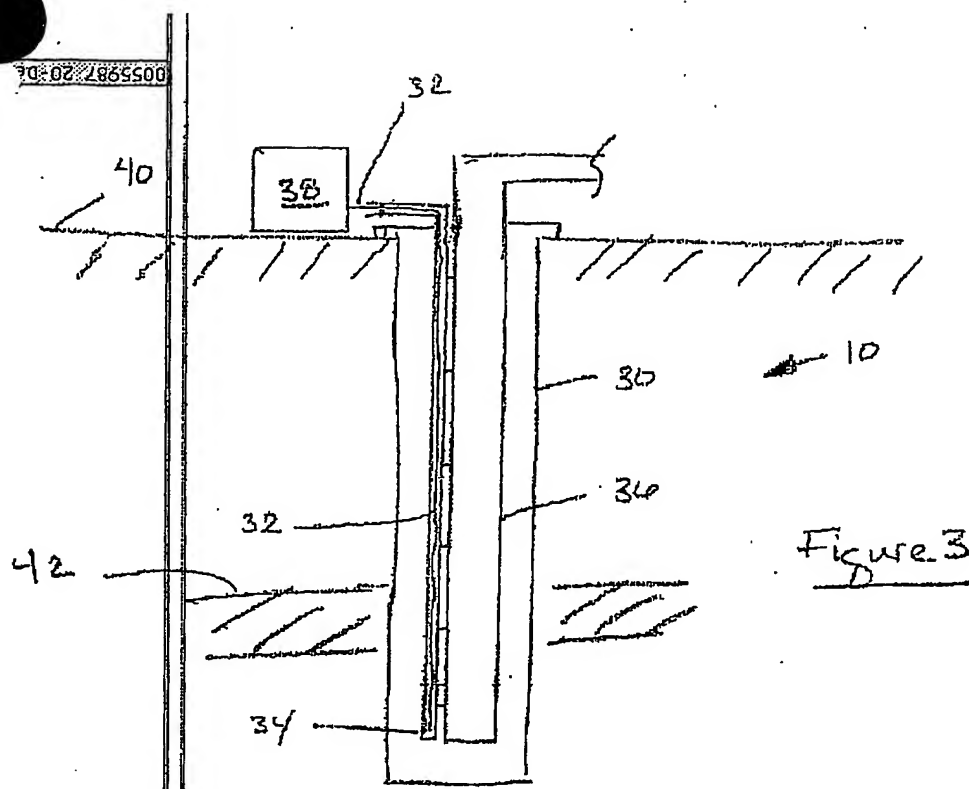


Figure 3

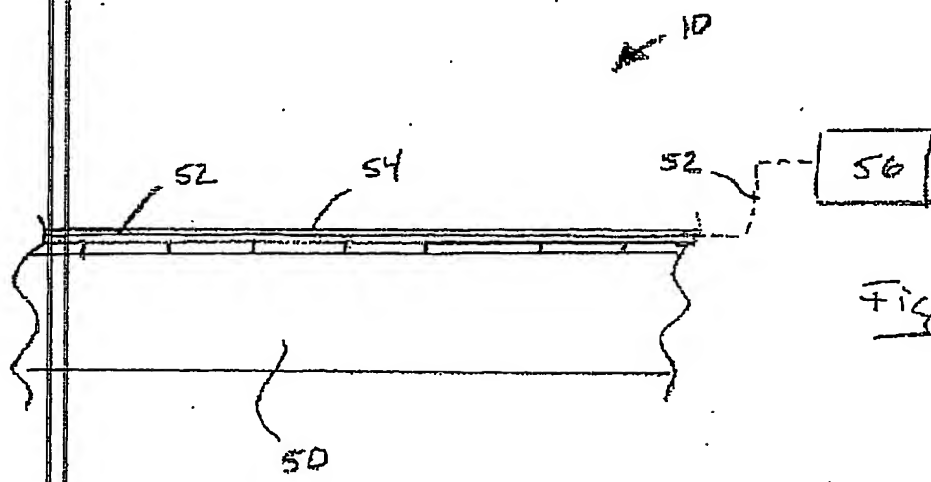


Figure 4

**This Page is Inserted by IFW Indexing and Scanning  
Operations and is not part of the Official Record**

**BEST AVAILABLE IMAGES**

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- ☒ BLACK BORDERS
- ☐ IMAGE CUT OFF AT TOP, BOTTOM OR SIDES
- ☐ FADED TEXT OR DRAWING
- ☒ BLURRED OR ILLEGIBLE TEXT OR DRAWING
- ☐ SKEWED/SLANTED IMAGES
- ☐ COLOR OR BLACK AND WHITE PHOTOGRAPHS
- ☐ GRAY SCALE DOCUMENTS
- ☐ LINES OR MARKS ON ORIGINAL DOCUMENT
- ☐ REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY
- ☐ OTHER: \_\_\_\_\_

**IMAGES ARE BEST AVAILABLE COPY.**

**As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.**